

## **Biological Engineering**

### **An Interview Study of the '12 & '13 Cohorts' Experience in 20.020**

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## Method

### Subjects

The 20.020 assessment study focused on the freshman student experience of the spring, 2012 and 2013 classes which included interviews and a survey administered at the end of the semester. Seven students from each cohort participated in the interviews that were conversational, informal, and ranged in length between 20 to 30 minutes. By means of several general open-ended questions the interviews explored the 20.020 learning experience, its impact, and students view of the experience. The interviews were audio taped, transcriptions were made of each session, and a content analysis performed on the responses [references].

## Results

### A. Student View of the 20.020 Experience

All the students spoke highly of the class; they were enthusiastic in their praise. As one freshman explained, I love the class. It is like my favorite class, I am not going to lie! Other respondents spoke similarly: *a) I really like the class. It was my favorite one this semester, for sure. b) The class is really inspiring. c) I personally really enjoyed it. d) My overall evaluation would have to be a really positive one.*

In the comments given below, the same strong sentiment is expressed, but with explanations of why students felt so passionately about the class.

*I think it is just a good setup where we did not really know much to start out with. A lot of the learning was actually all on us. We came in, had a couple random ideas, and were not really sure how the process would go. Over time, Natalie was able to guide us in the right direction to where she did not have to do that much teaching. She still taught us how the process worked but through our own knowledge and exploration. It was cool.*

*I really like this class. It is really interesting and something different than a GIR. It definitely has made the semester a little less dull. ... Taking this class [created] a level of excitement; MIT is supposed to be like an exciting problem-solving, stimulating place.*

*Exploring another field is not ... [something we did] in high school, and being able to work through problems by ourselves is awesome. I really love it.*

*I think the experience of being able to design something was the most important part. ... The whole creative process is really fun. Learning about synthetic biology is really fun. I learned about lot of stuff I did not know existed. And that is cool.*

...

*I very much liked the class. ... It has taught me a lot about working in teams, about designing things, getting over small problems, and synthetic biology in general. And it made me a lot more excited to take classes next year in biology and bioengineering.*

...

*It was a great experience for me.*

*We are doing a project right now that is really hands-on. I am doing the research, doing online research, soaking in knowledge that 7.013 could not pump into me. I am doing this myself.*

...

*If I told myself about our system in February, I would have no idea what I was talking about. I have learned a lot, in regards to bio and bioengineering.*

...

*The learning you do in 20.020, is, I cannot express it enough ... great, encouraging.*

*I like how we have a lot of freedom in our projects. I think it was very helpful because you learn a lot when you are thrown into it after a little introduction. Every member of my group declared Course 20. We all certainly really liked the class and benefited from getting a better understanding.*

In the seven sections that follow, freshmen interview responses are used to describe the experience and identify factors that led to students' responded positively to the experience.

## **B. Reasons for Taking 20.020**

At the start of 20.020, most of the participants were unsure whether to declare bioengineering or a related discipline as their major. Several other students were leaning toward bioengineering, and one student did not have a clear academic direction. Almost all of students took the class to help them decide which academic path they should follow. As one freshman explained, *I was interested in Course 20. I was between bioengineering and biology. I was not really sure which one. I had never heard of bioengineering before I came here, it sounded cool. It is engineering at MIT; I figured I should do something with engineering. I figured ... I would ... take the class, get a better sense of what bioengineering is, what you can do with it, and then decide.* For some students, they learned about the class by word of mouth. In some instances, the comments were accompanied with praise for the class:

*One of my friends who was in the course ... told me it was a good class, that it was an introduction to bioengineering. And I was debating between biology and bioengineering at the time. That is the main reason I took it.*

*I originally came into MIT thinking I wanted to be in bioengineering. But I was not completely sure because I did not know much about the field. ... Someone in my dorm said that they had taken a class with Natalie and she was great, and, she was [teaching] a freshman [class] on bioengineerng.*

## **C. Deciding on Major/View of Bioengineering/20.020 Excitement**

All the students interviewed declared bioengineering. They spoke enthusiastically about the class. When asked what advice they would give a freshman about taking 20.020, they responded similarly, *take it!*

*I would recommend every potential Course 20 freshman next year take this class.*

*If freshmen are interested in Course 20 and are unfamiliar with what Course 20 is about, definitely take 20.020.*

*I would tell them if you are very interested in what bioengineers do and what the field can do, ... you should take it.*

*If they were interested in Course 20, it is definitely an excellent introduction to what it is like. In the sophomore year, if you are in course 20, there is no specific bioengineering classes you take. ... You are taking a bunch of prerequisites. ... Until junior year, this is basically the [only bioengineering] class you will take.*

*It is really great even if you do not want to do course 20, just to see what course 20 is like, ... but also to be able to apply what you are learning in [biology] lectures and see how it actually can be used for real projects as opposed to just for tests. ... Even if you do not want to go through synthetic biology, there is still the whole design process, presenting and getting feedback. All of that is useful no matter what field you are going [into.]*

*Definitely. I mean I think if somebody is even remotely interested in course 20, it would be worth taking. It is not a huge burden on your schedule. And it is interesting, definitely worth it.*

One factor that contributed to students' selecting Course 20 as their major was the view of the field they gained from the 20.020 experience. The following comments provide examples of students' beginning the class with minimal understanding of the difference between bioengineering and related biological disciplines, and emerging from the class experience with a clearer view of the field and stronger interest in it. In the case of one student, *At the start of the class, I was very confused about what is the difference [between biomedical and biological engineering.] I have a friend who goes to Case Western and works more with instruments that go into the body artificially. But I really like how you can manipulate actual cells which is what we have been focusing on in 20.020. I do not really completely understand ... biological*

*engineering, but by taking the class, I am very drawn to it. Another student commented the different class projects made her aware of the scope of the field and how the field encompassed her other interest. Seeing the different projects we have done in 20.020-- one group is doing remyelination for MS, another group is trying to get drugs into the brain, and we are doing environmental stuff--it is cool to see that there is broad range of things you can do with bioengineering. That helped me decide [Course 20 as my major.] I was also thinking about environmental engineering ... but [I realized] I could do environmental stuff with course 20 as well.*

By the end of the class, students viewed bioengineering positively, viewed the field as one of potential and excitement.

*It is a very new field. ... There is a lot to be done. ... It is clear the field has potential.*

*Looking into the field of bioengineering, I never knew that this is what you could be doing with it, like designing these systems. ... I have learned a lot about the field and what you can do with it.*

*I feel bioengineering is an emerging field. ... It is ... an emerging field [that] has limitless potential. ... You cannot imagine what we can do with a single cell, with a circuit. ... Bioengineering will give me a lot of career choices. I like biology and would love to work with cells and DNA. Course 20.020 helped me; [it exposed me] to a lot of aspects of synthetic biology. ... Bioengineering is different from biology. You can ... [apply] mechanical engineering. You can apply those concepts, put circuits into cells, ... it is amazing.*

*Biological engineering is a really cool new field. It is still an emerging technology ... I see this as a new revolution. This field could be the computer revolution of the '70s or the '80s. ... That would be really cool!*

*This is really cool: The idea that you can engineer biology is fascinating.*

*The project I am working on focuses on the central nervous system. That is my interest. I like everything you can do within 20.020 and engineering biology. I think it is really neat. That is why I am drawn to it.*

#### **D. Class Atmosphere**

All the respondents found the class atmosphere relaxing, supportive, and intellectually engaging. No student made a statement that would contradict the view of the class as a positive, stimulating experience. In many of the interviews, students used the word, *exciting*, to describe the atmosphere. As one student explained, *when we you are doing hands-on stuff, everyone is pretty much excited. I think that is just the nature of the work. And everyone is like, "Oh, this is really cool to see as the end result." [For my group,] there definitely has been enthusiasm for the work we have been doing.* Another student commented the class atmosphere is *pretty loud. There are definitely times when everyone is bogged down trying to read through [articles,] then it is a little quieter. But when people find something, they are like, "Oh my God, I just found this. It is going to work." And they all get really excited.*

One student, but not the only student, explained that his excitement began early on the semester when the students were conducting several basic experiments that introduced them to synthetic biology. *We were doing simple stuff like extracting DNA from strawberries or doing lots of little experiments like a bacterial camera when we did recombinant DNA and e. coli. That stuff really counted with me. I thought, "Wow, this is really, really cool stuff." Then I was hooked, and really loved the class.* Another respondent offered a glimpse of the class by suggesting what would most likely happen if the interviewer were to visit the class. *I would assume if you went to any group and [asked] "Tell me about your project," they would all smile and be like, "Me first. Me first. Me first." ... Within our groups, we are excited about what we are doing. We are passionate about what we are doing.*

A significant aspect of the atmosphere is its intellectual energy, an energy that is central to the learning experience, inherent in project design, and a driving force in the team work. As will be



discussed later in the paper, this energy manifests itself in the way students interact with one another and collectively reason through design issues; as one student explained it, *Everyone is very interested about the ideas. There is an intellectual energy going on.*

*Stimulating! I mean definitely intellectually stimulating. I find the stuff that we are working on to be really interesting. It was something I never thought I would be interested in, like anemia, iron absorption, the way your body deals with that. I never thought I would be interested in anything like that. This class opened up the opportunity for me to learn about something like that.*

*When we you are doing hands-on stuff, everyone is pretty much excited. I think that is just the nature of the work. And everyone is like, "Oh, this is really cool to see as the end result." [For my group,] there definitely has been enthusiasm for the work we have been doing.*

*[When] I am talking to my parents at home, I will be telling them, "Look what I just did in this class. It is really cool. I think it is going to work." Whereas in other classes, for example, chemistry, it is lecture. I am not going to be, "Yeah, I learned that acids and bases do these things." But [with 20.020,] I was able to say, "[I] designed this and it was really cool." I want to tell everyone, "Look what I am creating." That is really neat.*

Students commented on several aspects of the class atmosphere that appear to represent conditions that contribute to the presence of the collective intellectual energy: safety, openness, and the absence of excessive amount of stress. These three aspects are interrelated. For example, safety relates to students' trusting the environment, seeing the environment as not antagonistic but open to their ideas, and having a willingness to receive criticism without shutting down. One student commented, *When we are presenting, it is a very open environment. I am not scared to present in front of the [other students] because they are all very positive. They give good feedback. It might be annoying at times to answer all their questions, but they*

*are all actually listening to what we have to say. It is not negative at all. ... I can share my ideas with any of them and will not get shut down. They will revise [the ideas] in a friendly way. It has been a really great environment. Another student's comment echoes the openness of the discussions and receptivity of hearing different views. I really like that atmosphere. It is really relaxing. After a few weeks we ... [formed] groups. We have discussions, and anyone can interrupt and raise... questions. I really like the interactive atmosphere of the class.*

Comments by two other students illustrate the interconnections among feeling safe, not feeling stressed, and learning effectively. One student described her learning as effective, taking place within a *laidback* atmosphere where the threat of serious consequences occurring if she were to make a few missteps was non-existent. *It is not like you are memorizing things and have to commit everything to memory for tests. We are learning as we go. We spend our time in class reading papers, looking things up, and learning all of that. It is not like ... you have to know all of this perfectly and if you mess up this little bit, ... you are going to fail. It is laid back. We are learning at our own pace. You are learning the stuff that pertains to your project.*

The comments of another student illustrate how the teaching philosophy of the class played a role in reducing stress. She commented that Dr. Kuldell explicitly made high quality work and learning the priority for students. And as the student emphatically stated, she learned.

*It was frustrating when you work for a long time on an idea, and it is not going to go anywhere. But Natalie is incredibly supportive. If we tell her something has gone terribly wrong in our project, she is totally fine with that. She helps us try and go in a new direction. We know we are not going to do terribly in the class because the idea we are working on does not work. So, we do not feel terribly stressed out. She has made it very clear that our projects are supposed to be high level, supposed to be about learning. We are not trying to actually pitch this to some drug company and get funding. It is much more low-key.*

...

*Her expectations are a lot about learning, not a final project. ... She is so supportive and really wants us to learn this stuff. She thinks every step we take is great. And we can tell*

*she thinks so. It is her supportive guidelines, the outline for the class expectations, as well as her demeanor when she is talking to us. ... It is very clear she ... wants us to learn above everything else, which we are definitely doing!*

It is difficult to imagine that the high degree of collaboration that occurred within each project team could happen without the presence of safety, openness, and absence of stress. The high degree of collaboration among the students is discussed in a later section.

### **E. Role of Experts**

All the respondents spoke enthusiastically about discussing their projects with experts. Students described the experts as *supportive, awesome, and incredible*, and described the experience as *cool, helpful, interesting, absolutely super useful, very informative, insightful, and inspiring*. The experts were generous with their time. They listened to their presentations, challenged them, identified design problems, offered solutions, and suggested alternative strategies. They respected the students' ideas, engaged them in conversation and described their own work. The result: students felt inspired, energized, and affirmed. The interactions made students realize how much they had learned, that they could converse with experts on scientific topics, propose ideas that would be taken seriously, and understand the experts' feedback on design problems and new directions.

*I was surprised. I do not know what I expected. But they were really, really open to listening to what our ideas were and provided good feedback. [It] did not seem [they felt] they were talking to little kids. They treated us as equals because we had good ideas. They were willing to listen. That was really cool. ... We expected they would be like, "Oh yeah, little kids working on their projects. Good for you." But they [responded,] "This seems really interesting. ... [You] should fix this, but [the project] seems really cool." They listened to us and helped us a lot.*

*Hearing them talk, the sheer fact of their talking and my understanding what they are saying makes me smile because they are experts.*

*They looked at our system and knew what we were talking about, which is pretty cool. Also, they were willing to help. They thought our project was cool, and they told us, "This is a good idea. You are doing a good job. This is really useful. I am interested in what you are doing." And that was really nice.*

*They were very helpful in answering all our questions and offering advice, offering alternatives to what we had thought, as well as bringing up problems that we had not thought of.*

*He was very supportive. He thought it was cool that we were doing this class. He had a lot of ideas to help us through. He would talk a little about a certain molecule, and then ask what we thought about it. He was very interactive, and inspiring.... He mentioned a few things they were working on in his lab that were high level ... it was cool to [hear about his] ideas and the things he is working on.*

#### **F. Role of Student Mentors**

The students appreciated the contribution the mentors made to their learning. As one student commented, *They are a big part of the class.* The mentors functioned as resources, teachers, and, at times, mediators. They guided the teams through the design process, providing support in the brainstorming, researching, and troubleshooting phases of the projects. For example,

*They help us dissect articles. ... But they are not doing the research for us. The five of us are doing the research. If we have a question, we more than likely go to them. They are very willing and helpful. ... They are mentoring us.*

*They helped guide us through parts of the project [where] we were not sure, ... [lacked the] experience they had. ... They helped us find papers that could be useful.*

*They had lots of great ideas on how to streamline our project. ... They have worked with this stuff before; they have taken the lab classes.... So they could say, "All right, that is going to work in the system. That might not work in the system. We have not tried that yet."*

*The mentors did help. They helped us come up with the original idea to do this project; the idea was inspired by a discussion with one of our mentors. They kept us on track. They would ask us, "Oh, how is it going? Is everything working?" Then, we would have to stop whatever we were doing and make sure that everything was working, and usually [we would] find problems. So, they were definitely useful. They did not solve problems for us, but they helped us to solve our problems.*

*[When] we talked with our mentors, ... [we explained,] "This is what we know. This is why we think this is our best option." .... [We] put all of what we had on the table and [with them] sift through it.*

*Sometimes there was no elaborate explanation for the thing we were looking for. Then we turned to our mentors. They are experienced, had read a lot of papers, and were able to explain things*

When students were in trouble, when they were stuck, when they needed support, the mentors came through.

*They are awesome. They are always there to help us. They have met with us on Sunday nights at 10:00 to go over our presentations two days before they were due.*

*They have been helpful throughout. We emailed them a lot. We would contact them [and they would] come. They are only supposed to come on Wednesdays to help us. But, ... they have come on Tuesdays, ... [and] on Thursdays when we really needed help. My group definitely appreciates the help our mentors have given us. They have definitely*

*spent a lot more time than we thought they would. They are definitely putting in a lot of time. And it is really appreciated by the whole group.*

The one exception to the positive view of the mentors was one student who, although appreciative of the Course 20 advice, commented that his mentors were *easily distracted*. *So they have not been terribly helpful with the actual project itself. ... The other mentors are incredibly helpful. They will do extra to help the kids.*

## **G. Team Experience**

### **Team spirit**

The students enjoyed working in teams, bonded with their teammates, meet with them outside of class, and found the experience positive. The one exception to having a completely positive experience was a pair of students who had a personality conflict. All the students developed new friendships as a result of their team experience. The comments below illustrate the close connection among team members.

*Everyone in the class was pretty happy with their groups. We ended up working together with people whom we did not fully know before. We got to know [one another] better ... by working [together] ... in and outside class.*

*I like all the people in the class. The majority of us are going to be Course 20. We are going to be taking the same classes next semester, and the semesters after that. It is good to have a good, close group of friends already.*

*I love my group. We spent a lot of time in and out of class because we wanted to polish our project. Usually, we met Saturday or Sunday morning ... to discuss, make our slides, and have brunch. Before the presentations, we usually would have two nights rehearsing. We spent a lot of time on our project. Our group has been unified. I like the people. When we encounter ... a problem, we brainstorm and come up with different strategies to solve it.*

*I love my group. We are a really good team. We work well together. We have definitely become closer over the semester.*

### **Abstraction Hierarchy**

Each team drew upon the abstraction hierarchy to guide their designing and specifying a biotechnology. The following comments by two students illustrate how teams used the abstraction hierarchy to develop their project. In the case of the first student, he provides an overview of how his team progressed from not knowing one another or *anything* to identifying a project to specifying the biotechnology in terms of parts, devices, and DNA.

*When we [began working] in our groups, we did not know anyone or anything. The mentors sat with us, and said, "Let us just brainstorm. If you could do anything with the human body, what would it be?" We [generated] this long list ... that sounded really cool. ... We narrowed the list down to [projects] that seemed could ... work. From there we voted for the ones ... we were most interested in. That is how we got our top three.*

...

*We then split up into groups of two, and [each group worked on one of the three ideas] and presented it to the class. We [received] feedback from Natalie and from our peers saying, like "This one probably will not work. [Or,] This one sounds like it could." [Based on the feedback,] we decided to go with anemia.*

...

*[Then] we had to figure out devices and parts and the general overall black box system. From there, we ... figured out the DNA, promoters and regulators, and how are things going to work at the DNA level.*

In the comments of the other student, we begin to see a team's reasoning as it follows the abstraction hierarchy. *We started all the way at the highest level [of the abstraction hierarchy,] ... [which is describing] what you want your system to do. For that, ... [we worked on] a three ideas presentation. I was in a group where we decided ... to work on improving human performance. The three ideas our group presented were [bone regeneration, ... iron absorption, and ... allergies. The team ended up choosing iron absorption. For the project, the students*

designed a system that ... would take in iron and deliver it right to the duodenum where it is absorbed into the body. ... [After identifying the function of our system,] we worked our way down, "Well now we need the devices to do this. We need something to take iron into the cell. We need something to store iron. We need something to release iron." Over time relying on the abstraction hierarchy, we worked our way down getting more and more specific ... down to parts. Parts are like, to take iron in, we need to use siderophores. And for one part, the team worked it all the way down to the DNA sequence of [the] system.

## **Challenge**

Even with the abstraction hierarchy as a guide, the students, at times, found the demands of the project difficult, frustrating, and daunting. One student described well how the project tasks may have appeared to many freshmen. *I never had to do anything like this before. So it was a new experience. It was harder than I thought it would be to [put] things together that would work to achieve our purpose, and not interfere with each other or have all sorts of horrible things happen. ... Kind of frustrating ... Searching for what we needed was hard. ... Once we found articles, reading through them and trying to figure out if they were actually relevant, which most of them were not, was difficult.* Another student's comments illustrate how the abstraction served as a guide and not as a recipe of exact steps that would minimize the intellectual challenges students faced. *We [divided] the project into steps. First, [we asked ] what do we want the system to do? [Following Natalie's abstraction hierarchy,] was very helpful because my project is remyelinating axons. Thinking about how are we going to go about doing that was very overwhelming, especially, [when] we did not know much biology.*

The last sentence of the previous student's comments captures a critical aspect of the project experience; students were not undertaking a simple task. As one student explained, *There definitely were challenges. There were several times when we thought we had our project completely figured out. And we were like, "Oh, wow. We are done so early. This is great. It is going to work." And then we would find out, "Nope.": It is not going to function because we ... [had a] completely wrong part. We felt ... [it is all] over. ... It not going to work out. That was definitely hard, to ... take a few steps back, reconsider our system as a whole, and work back up*



*again. That happened a few times where we thought we had it figured out, ... [but we had] missed one little piece.*

Although the projects posed challenges, the challenges were compounded by the freshmen sometimes underestimating the difficulties of the design task. As one freshman explained, *The schema was very helpful for me because when we first started, we just black-boxed it, like this is a device. And I was like, "Oh, this is really cool. This is the input. This is the output." I [thought,] "That is really easy." And then, when I got into it, I am like, "Okay, that is a lot more work."* Along similar lines, a freshman commented, *In the beginning, we are working on a project, thinking "Oh, yeah, sure, that project seems pretty simple ... we can do it." But, as we read more and more, more unknowns came up, getting more complex every day. ... Having [to think up] the design was not very difficult. ... But finding the parts so that we can make it [work] was very challenging.* A third student commented on the consequences of his team focusing on a disease whose cure remains unknown. *We knew it would be hard, coming into it. Our team decided to work on a human disease. It dawned on us that there is a reason certain diseases have not been cured already. It is because they are difficult to [cure]. So our project hit a lot of snags in the road.*

Even though there were times when students felt frustrated or overwhelmed, overall, they enjoyed the experience and learned deeply. (See student view and class atmosphere sections.) When teams resolved the challenges they faced, when they experienced discovery, they experienced joy and excitement. *It can be frustrating sometimes when we keep running into problems and have to solve them. But, it is always exciting trying to find a solution. Especially, when you see how far the project has come since the first couple of weeks when we started. People are starting to get really excited about the project. ... There is always something new. We would brainstorm, pick an idea, and find different devices. It is always exciting when people find something new.*

## **Collaboration**

In spite of the difficulties the projects posed, team members did not become competitive, express anger, or act out their frustration toward one another. On the contrary, the students, most of

whom did not know one another at the beginning of the 20.020, formed effective teams. Except for the two students whose team experience was mixed due to their personality conflict, every student strongly praised their team's collaboration.

As part of their collaborative spirit, students divided up both the class work and homework they assigned themselves. The following examples illustrate how teams shared the workload:

*We start with, "okay, four things we want to get done today. We want to know this before we leave. We want to know this before we leave." ... "Okay, so [student A] is working on that. [Student B] is working on that. [Student C] research this.*

*We would split up a task for a night, and then the next day we would get together and present what we found, and then pick from what we found, what was actually useful.*

An essential aspect to students' dividing up their was their sharing the information they learned in order to ensure that other team members also understood the material they researched.

*We started by designing our general idea of the system, an abstract version of it. ... [We first identified] what we wanted the system to do. Then we focused on how we would actually get it to do that. We split up into smaller groups. ... [For example, another girl and I] worked on the calcium detector, ... someone else worked on iron storage and iron cell. Other people worked on iron release. ... We made sure we shared what we were finding with everyone. That way when we made presentations, if there were any questions, we would all be able to answer them without [responding,] "we do not know."*

*[For the readings,] we usually split into groups. Some are working on the sensor to understand how the hydrocarbon is processed in the cell. I am working on the [cell-]death device. And some are working on the inverter, how to trigger the promoter, how to make [everything] work. So we split into different groups. ... After we develop [our] ideas, we share the information. On one hand, I gain a really deep understanding of my*

*[area.] On the other hand, when we share our information, I [learn] how the things work [in the areas] the other [team members] researched.*

*If there were a deadline, and someone said, “I am not going to be able to get this done. Can you help me?” Another member of the group would jump right in to help.*

## **Group Thinking**

Central to students' collaborations was their bouncing ideas off one another. *Every group is doing that, I am sure. Every group is really working the same way that we are working, bouncing ideas off of each other.* The comments below highlight the bouncing ideas off one another as a process that includes team members discussing, learning, and teaching.

*They thought of things that I did not think of, and vice-versa. [The group work] definitely promotes the fact that science is a collaborative environment, that you cannot go nearly as far by yourself as you can with [others.] Having differing perspectives, I mean two heads are better than one; you can get more done, productivity-wise. Being together you can play off each other's ideas, and go from there. Someone comes up with something, and it is like, “Oh, we never would have thought of that.” ... It is definitely nice to have a team of people working together.*

*You are looking at articles, understanding the material, and putting a system together with your team ... you learn a lot. I have learned more from the four members of my group than I have from the research online. They have [taught] me different things ... or maybe something that I did not hear in bio or did not grasp.*

*If you are working by yourself, you cannot bounce your ideas off of other people. You may have never thought of something that someone else thought of. You have to be mindful that you cannot do everything yourself.*

*I think the different perspectives have been really helpful because different perspectives always make you see things differently. Something I would have never thought of,*

*someone else might have. ... I do not think [different opinions] hindered our group. I think they only helped us.*

Inherent in the process of students bouncing ideas off one another is a shared value of openness: respecting one another's ideas and challenging ideas of others in a constructive manner. In the four sets of comments that follow, the freshmen discuss being open to all ideas, overcoming fear of expressing an idea, and not responding negatively when their ideas are rejected.

*We are very open-minded to everyone's ideas. If anyone has an idea, we will at least look into it, unless we know that it will not work. Our group is very good at putting things in perspective.*

*I am in a great group. I like all the people whom I am working with. We work well together. I was one of the people who was quiet in the beginning. ... After a couple classes, I was like, "These people are really awesome. They are not going to judge me if I say something dumb." ... I am a lot more comfortable working with people here. When I came to MIT, I didn't feel as smart as the people around me. For the first half of the year, I was pretty iffy about group work. ... This class definitely made me more confident in what I can do.*

*We actually listen to each other. We think through things logically and do not get upset when our idea gets thrown out because it just is not going to work. We have a lot of exciting discussions about "Well, this could work. Well, this could work also. Well wait, this idea could work too." And then we have a whole bunch of possible ideas. Then we ... go through [them.]*

*The best thing for a group is communication, [asking] what are your ideas, voicing your opinion [about] where the project is going, where the group is going, being very open with the other four people. And we definitely have that.*

Closely related to being open to the ideas of others is letting go of ownership of one's ideas.

For example one student, commented, *We cared about what we were doing, but we were not, possessive of ideas. It was not, "This is my idea. You cannot ruin it by suggesting your idea." It was like, "Let us suggest all the things and make something that works."* Another student commented, *We cared about what we were doing, but we were not, possessive of ideas. It was not, "This is my idea. You cannot ruin it by suggesting your idea." It was like, "Let us suggest all the things and make something that works.* Another freshman gave an example of his letting go. *Our group is very open-minded. For example, I was not offended that my system, the part that I had been working on for so long was not going to be in the final system. I thought, "Okay, I will go learn about siderophores and see if that works too. And, as long as a bunch of us can agree that this idea will work, we just leave it until [someone] finds out otherwise."*

When teams encountered setbacks or were uncertain about which direction to follow, the members expressed different opinions of how to proceed. One student explained that for his/her team, *did not all have the same idea of how we would accomplish our goal. But, by taking little bits from everywhere, it is definitely made us see [whether] this is going to work, not going to work, or could we fix a part of it.* Another student offered similar comments, *We realized that, in order to get the project done and to find a solution, we had to find common ground and agree on things. It was a lot of discussing and throwing out ideas. I definitely got a lot more comfortable with throwing out my ideas, even if they were to get shot down right away. It is helpful to have six people with different thought processes; together, we can figure out which [ideas are] the best.*

The teams resolved conflicting positions with data, finding evidence from the literature that would support their views.

*When we have different opinions on [a topic], we usually split into two groups and do a lot of research ... [in order] to prove our idea is right.*

*There were a couple of people who had been ... more emotionally invested [in their ideas.] Over time, once they learned what this project was about, they also realized it was cool. ... Any of the three projects would have been neat. It was just that our [idea]*

*was the most viable and [the group] had the best chance of success with it. And I think they realized that. ... The best way to bring [those who preferred another project] on board is to bring them up to speed ... to explain why it is right, to give them solid information to back up your opinion. Otherwise, [they think] why is this person saying what [he/she is] saying. If your opinion has any real weight, you should be able to back it up. Over time, they were able to see that this was the most viable [project idea] because we gave them a lot of information. And they started doing research about it themselves and finding out more about it. Once they were brought up to speed, it was much easier for them to be onboard.*

*It is a majority vote on what we should do. I do not really know how to describe what we do. I guess it becomes obvious what the right answer is. Or, if we have different ideas, we will research them more. For example, for our first presentation, we had two different ideas for a sensor. And one person was working on one sensor, and another person was working on another. We ended up presenting both ideas. Eventually, after doing more research, it turned out that one [sensor] was better than the other. [In general,] with the research that [team members] do, one person will realize that something is not feasible, or another person will realize that something else works better. We never really fought about anything.*

### **Impact - students feeling empowered**

As a result of the stimulating class atmosphere, dynamic group collaborations, and effectively meeting the challenges the projects posed, students felt empowered. This impact was most noticeable in the '13 cohort interviews that explored the topic more deeply than in the previous year. The topic was explored without using the term, empowerment. Yet each student, in his or her own way, made comments that reflected their feeling empowered. For example, one student spoke of the affirmation felt by talking with an expert who praised the group's work, work which was in a field unfamiliar to the students when they began the class. *It was affirming because the expert was very interested in what we were doing. We received a lot of praise for what we were doing. The fact that we did not know anything [at the start of the class,] had an idea, and were*

*able to find something that even an expert in the field sees as a possibly viable thing to do is pretty cool. It is like, all right, I almost know what is going on.*

The student continued, commenting on a confidence that came from his sense that although bioengineering is a difficult field to grasp he could.

*A sense of confidence. You can start out with very little knowledge, and, over time, develop an expertise in the subject; ... that is kind of cool; and, also, that bioengineering is [no longer] that foreign. It is foreign until you start investing some time into it. And then it is a completely understandable subject. Bioengineering is [viewed as the] biology of the future and very difficult to understand. People spend their entire lives devoted to it. And it is not something that a group of 19 year olds should be able to understand. But, it is manageable if you put the effort into it. I think that is cool.*

The comments of three other students illustrate how empowerment emerges by doing; by relying on themselves, they were able to design a biotechnology in a field about which they knew little when they began. The sense of reliance can be clearly seen in the words of the first student: *Mostly what I have gained ... is understanding the broad mechanisms. ... You are relying on yourself and your team to think things through. You do not have a teacher going through the problems with you.* With the second student, empowerment occurs as a result of developing a project based on student ideas, creating a system that works, and discovering what can be achieved even as a freshman. She concludes by envisioning that in future she will be able to create actual biotechnologies. *The projects [were based on] our own ... ideas and we see them all the way through. ... We created a system that works. We are not actually [developing] it, but we have the whole plan for it. Seeing that we can do this with the limited experience we have, that we can come up with a whole idea, I think is awesome. With more experience, when I take more classes, I feel I could actually create something real.* The third freshman summed up students' sense of empowerment succinctly when she commented, *Seeing [our] progress ... made it... inspiring because [you think], "Okay, maybe I can do this."*

Beyond a general sense of empowerment, students spoke of specific areas where they felt empowered: gaining a deeper understanding of biology, reading scientific journals, presenting

persuasively, and working effectively with others. Comments by several students illustrate how the project experience deepened their understanding of biology. For one student, her project provided her with an example of how the material she learned in freshman biology relates to real world problems. *I definitely have become more comfortable with biology. I took 7.012 first semester. We learned about the stuff we are now using. But [in 7.012,] we just learned it through a textbook. Now, we are creating a project where I am actually understanding ... how it is used in real life.* For another student, as a result of her project work, she gained *a lot of knowledge about understanding systems and how you can manipulate them which was very foreign to me before I came to MIT. ... Learning about the systems and how you can get more in depth with them has helped me understand more aspects of biology.* And, in the case of a third student, when a topic related to her project was discussed in the biology class, she had a foundation to understand it. Moreover, by understanding the lecture, she was inspired. *It is really interesting because I am taking biology right now and we had a lecture on programmed cell death, apoptosis. And, because of [my 20.020] project, I had looked at a lot of papers about different models people have used for killing a cell. That gave me a foundation and inspiration when I listened to the bio lecture. I knew what was going on.*

The three other areas where students felt empowered are activities central to the project work: reading professional journals, presenting ideas, and working collaboratively. When asked what she gained from the 20.020 experience, one student commented, *Presentation skills for sure. ... I am definitely more confident about presenting. ... I am a lot more confident in my [ability] to have ideas and be able to talk to people about them.* When asked a similar question, another student responded, *I really learned more about organizing and presenting ideas. ... I am more comfortable trying to persuade people of my position. Now, I can definitely back up my ideas better with solid research. ... We are not using Wikipedia, we are using actual journals.*

The comments by this second student highlight the role of reading professional journals: students defend their ideas with the evidence they discover from their reading. Reading scientific journals is not an easy task for freshmen, but it is an essential task and one in which they gain confidence with practice. As one student explained, *I have never done scientific research in high school. ... So it has been pretty helpful to have to go through articles and work*



*our way through phrases we did not know what they fully meant. ... We are definitely getting use to how we can do real research. We are still using Google, but [we are] working our way through scientific articles that ... we do not fully understand. But we have to work through them and learn how to read them in the right way.* Comments of two other students echo the view that over time reading professional journals becomes easier.

*[Reading journals] started out a lot harder than it ended up [to be.] ... At first, there was a lot of scientific jargon ... that I had not really seen before. But, over time, you [begin] to put the pieces together. And now, it is like, "Okay, I understand what is going on, and how this happens."*

*Definitely reading research papers has become a lot easier.*

Several students spoke of the gains they made by working on teams. As one student simply expressed it, *Definitely by working in a group, my skills set improved a lot, teamwork in general.* On the surface, one could challenge whether the following comments reflect a student feeling empowered because he is identifying areas related to working in teams where he needs to improve. *I learned about group work. ... Definitely. I feel that sometimes I am a little too lenient, a little too nice. I hate arguing with people. I like to compromise and [make] everyone [feel] happy. But sometimes it does not work, especially when you are doing a project. ... One thing I took away from working in the group is that I have to [to express my views more directly] and take more of a leadership role. ...* But it is only through such experiences are learners able to feel empowered. In the case of this student, he went to say, **EE20.WkInGrps:** *One of the really good things about 20.020 is that we started our group project pretty early on in the semester. And this whole semester has prepared me really well for future group projects.*

In the comments of a third student, gaining the ability to work in groups was what was most important to her, a gain that came from working on a team, and a gain she believes prepares for group work in her major. *I think mostly what I have gained is the ability to work in a group. ... I am really close with my project group. We work really well together. Even if there were people*

*[with] whom you did not work very well ... [early in the semester,] you learned how to work together, which I think is really important, especially in Course 20. . [This] is a very collaborative field and we are going to be doing a lot of group projects ... in the next three years. So, it was really important to get exposure to that.*